TECHNICAL REPORT 400-150

ON THE RECONSTRUCTION OF OBJECTS FROM THEIR PHOTOGRAPHS

Andrew D. Rabinowitz

November 1966

LABORATORY FOR ELECTROSCIENCE RESEARCH

DEPARTMENT OF ELECTRICAL ENGINEERING

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ABSTRACT

This is a preliminary investigation into the area of the reconstruction of the three-dimensional description of objects from their photographs. Possible assumptions which *might* be made, the variables which are involved, and the limitations which exist are discussed. A literature survey is included in the appendices.

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I. INTRODUCTION

This report is concerned with the problem of reconstructing three-dimensional objects from their photographs. This problem can arise in several situations. First, an object might no longer be physically available as in the case of views from high-speed photography, pictures of deceased people, or a photograph of a burning building. Secondly, the object might be in a location in which the only way of obtaining information about the object is through photographs. Examples of this might be objects in outer space or in the deep ocean, Microscopically small objects would also be in this category. A third situation might be the area of data storage. This would be analogous to the way in which photographs are used for identification, with a human doing the reconstruction. To store the same information in words and numbers, if possible, might require considerably more storage space.

For purposes of this work it is convenient to divide all three-dimensional objects into two groups. The first group consists of polyhedral objects, that is of objects whose surface consists of a finite set of polygons arranged so that every side of every polygon is common with one and only one other polygon and that no subset has the sane property. The second group consists of all other objects. Members of the first group would be cubes, prisms, staircases, most houses, and an Allen wrench; members of the second group would be bowling pins, human faces, cups, and most living objects.

It is of importance to note that there are many objects which may be regarded as being compound objects, that is, objects that can be separated into polyhedral components and non-polyhedral components,

It would appear that the best methods for reconstruction would be different for the two groups. For example, the sharp boundaries present in the members of the first group should certainly be used in *any* reconstruction method of objects in this group.

There are many factors that determine the amount and type of information which is available from a two-dimensional photograph (or photographs if possible). Among these are: 1) lighting, 2) size of the subject relative to the distance from the camera and the focal length of the lens, 3) views shown, and 4) th& settings of the camera which effect focus, depth of field, and blur due to motion. It will be assumed that the film offers no limitations (in practice the large number of available films makes this a fairly reasonable assumption), and that the optics introduce negligible distortion. Furthermore, it is believed that perfect exposure in making photographs is not necessary for achieving reconstruction. It is obvious, however, that extremes of overexposure or underexposure would lead to errors.

There are several possibilities with respect to the conditions under which the pictures are taken. First, there may be no control over what pictures are taken and no knowledge of the lighting and camera settings. In the second case, there may still be no control over what pictures are taken, but the camera settings and lighting conditions are known. In the third case, complete knowledge of the circumstances of the photographing Is available, possibly because the photographs were made "to order". This last case is obviously the most desirable.

One additional condition is involved. Prior knowledge about the subject may or may not be available, This knowledge could take the form of a known axis of symmetry, a relationship between parts such as "in front of", or a geometrical restriction such as "simply connected",

II. PHOTOGRAPHIC CAMERA VARIABLES

There are four camera variables to be considered: shutter speed, effective lens diameter, lens focal length, and the distance from the lens to the film plane. Shutter speed should be set fast enough to eliminate blur due to motion. No other restriction would seem to be necessary (except as noted previously for gross overexposure or underexposure). The remaining variables control the depth of field, the amount of magnification or reduction, and the size of the field of view,

Concerning depth of field, two possibilities seem to be worth considering. The first is a very short depth of field. This would be useful if a method were available for determining what part of the image were in Focus. This would serve to determine the distance from the subject to the camera. Another possibility with shortdepths of field would be the use of a series of pictures to determine the relative position of objects or parts of objects. The wide depth of field, with everything shown in the frame in focus, would be desirable in other cases. This would yield the sharpest possible edges, faces, and other features for accurate reconstruction,

III. LABELLING SYSTEM FOR POLYHEDRAL OBJECTS

The following labelling system will be used for polyhedral objects. The faces (polygons) will be assigned Arabic numerals 1,2,3,...,n such that n equals the total number of faces, but with no other restriction. Boundaries (edges) will be referred to by the names of the forming faces so that boundary 14,7 is between faces 14 and 7. Similarly, vertices will be indicated by the names of the forming faces. Hence vertex 3,6,21 is the intersection of faces 3, 6, and 21.

If more than one object is present in the photograph, each will be assigned a capital Roman letter starting with A for the upper left-most object and proceeding first top to bottom and then from left to right with B, C, D, ... These object names will be prefixed to the above face boundary, and vertex names as follows: face A1, boundary A14,7, and vertex A3,6,21.

An illustration of this labelling system is given in Fig. 1.

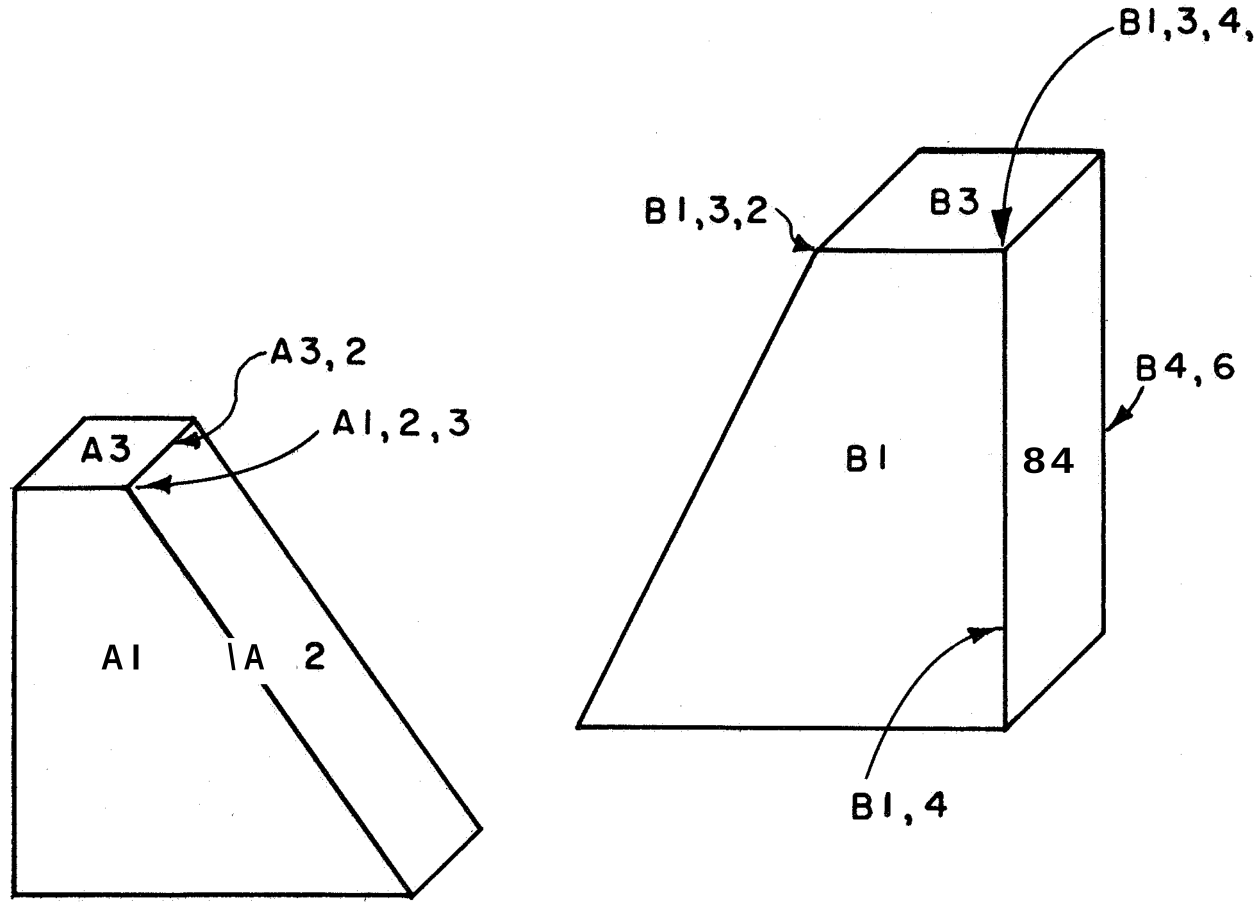


FIG. 1

EXAMPLES OF THE LABELLING SYSTEM

FACE: A1

BOUNDARY: A3,2

VERTEX: A1,2,3

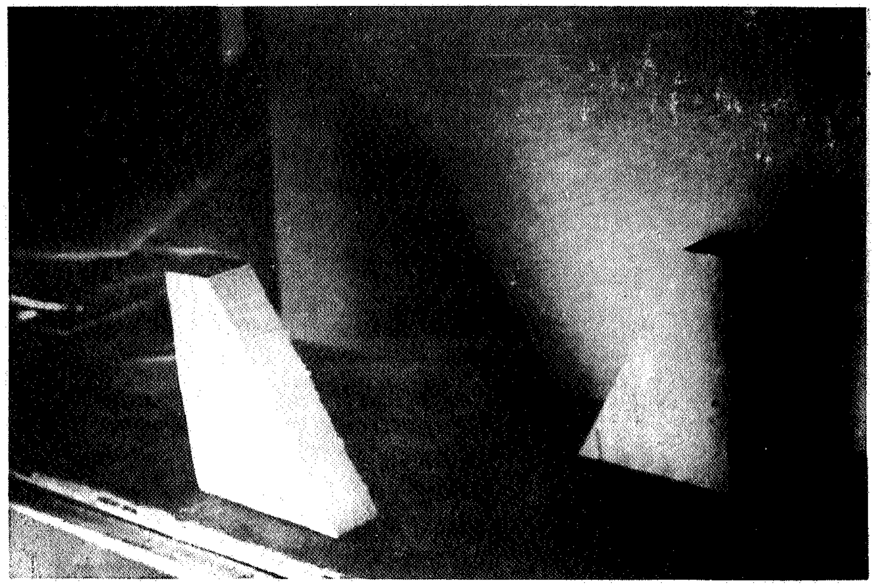
IV. EFFECTS OF LIGHTING CONDITIONS

Lighting conditions must be considered because they can have confusing as well as clarifying effects, Examples of the former would be the hiding of line B4,6 in Fig. 2a, or of line A3,2 in Fig. 2b (for labelling refer to Fig. 1). An example of a clarifying effect is shown by face A1 in Figs, 3a and 3b. In Fig, 3b, face A1 appears as a uniform surface, while in Fig. 3a the texture of the face has taken on characteristics similar to edges.

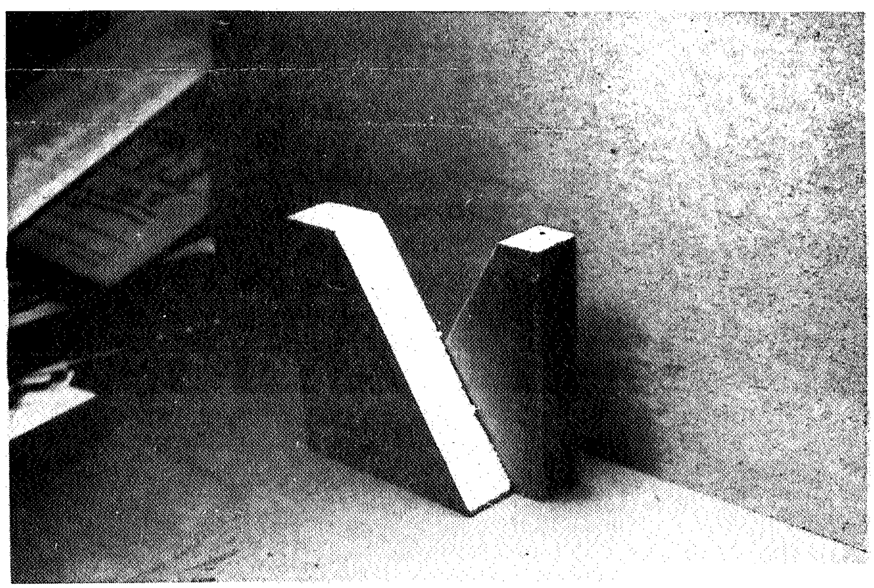
There are three main lighting variables that can affect the appearance of the image in a photograph:

1) The orientation of the light source(s)* with respect to the axis of the lens.
2) The distance from the light source(s) to the subject.
3) The number of sources.

*Note that reflecting surfaces my produce results similar to those produced by sources.



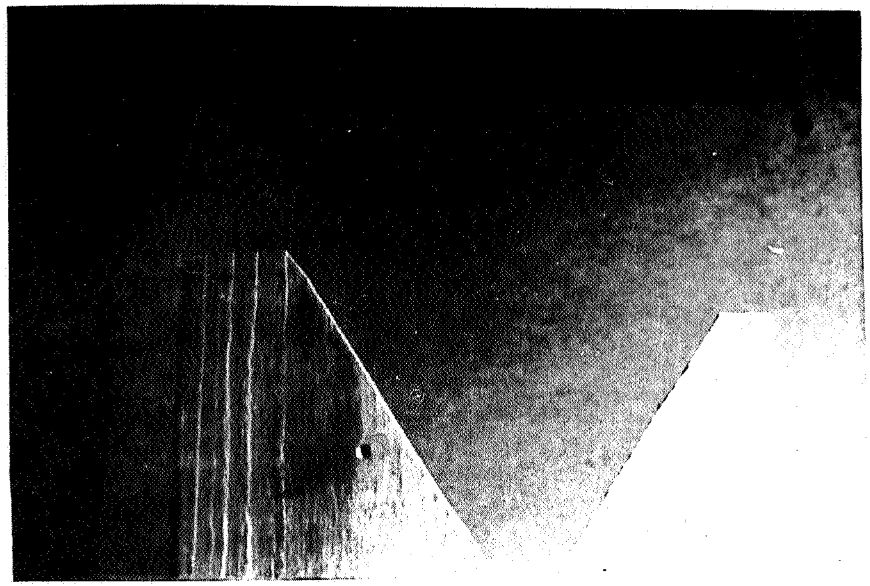
(a)



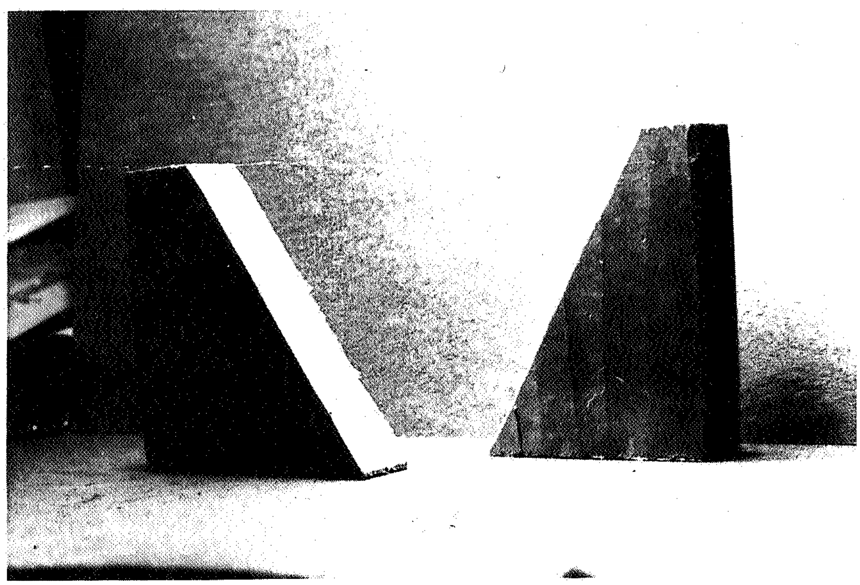
(b)

FIGURE 2

EXAMPLES OF LIGHTING CONDITIONS CAUSING EDGES TO BE HIDDEN



(a)



(b)

FIGURE 3

EXAMPLES OF LIGHTING CONDITIONS HIDING CONFUSING SURFACE TEXTURE

V. PRECEDENCE DESIGNATIONS

The following method is introduced to provide an orderly and compact way of ordering sections of objects, especially when more than one object is involved.

Consider two sections X and Y and their non-common parts $X \cap (X \cap Y)' = X \cap Y'$ and $Y \cap (X \cap Y)' = Y \cap X'$. Let w be an arbitrary direction. Then $P_w(X \cap Y')$ is defined as the orthogonal projection of X on w. There are several possible relationships between $P_w(X \cap Y')$ and $P_w(Y \cap X')$ along the w axis, as illustrated in Fig. 4. A compact notation for each relation is also shown in this figure,

A number of points should be made clear. First, X and Y can in general be *any* type of convex or non-convex section, Second, X and Y need not have more than three points in a common plane, and this is necessary only because three points determine a plane, Furthermore, this plane does not have to contain w. Third, in many cases, such as for sections which are planar faces, determining the precedence relation is reduced to an end point comparison,

Using the notation of Fig. 4, the following expressions may be written:

(1) $(X < Y) \;\&\; (Y < Z) \rightarrow (X < Z)$

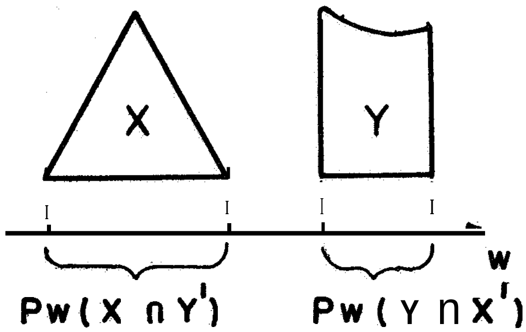
(2) $(X = Y) \;\&\; (Y = Z) \rightarrow (X = Z)$

(3) $(X \lesseqgtr Y) \;\&\; (Y \lesseqgtr Z) \rightarrow (X \lesseqgtr Z)$

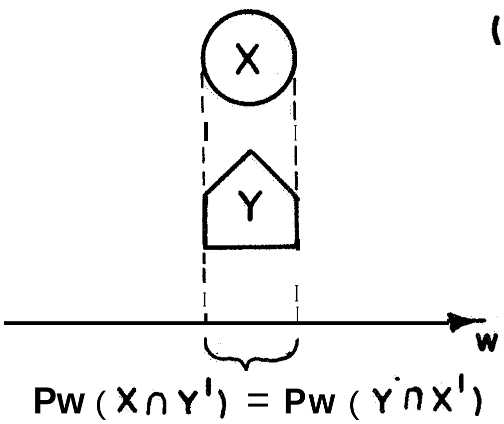
(4) $(X \geq Y) \;\&\; (Y \geq Z) \rightarrow (X \geq Z)$

(5) $(X \leq Y) \;\&\; (Y \leq Z) \rightarrow (X \leq Z)$

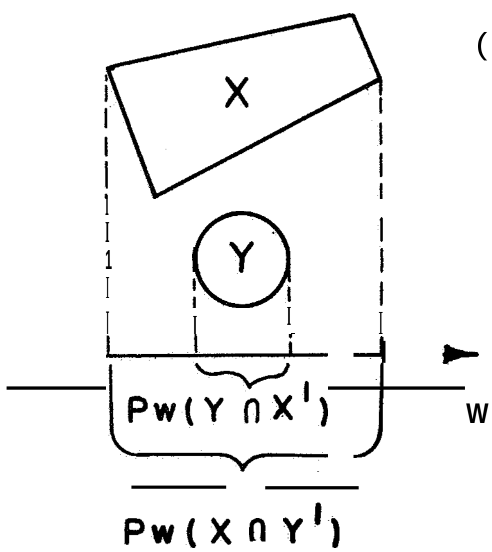
(6) $(X <> Y) \;\&\; (Y <> Z) \rightarrow (X <> Z)$ or $(X < Z)$



(a) THE PROJECTIONS ARE DISJOINT AND X PRECEDES Y ALONG THE w AXIS.
NOTATION : X ⓐ Y



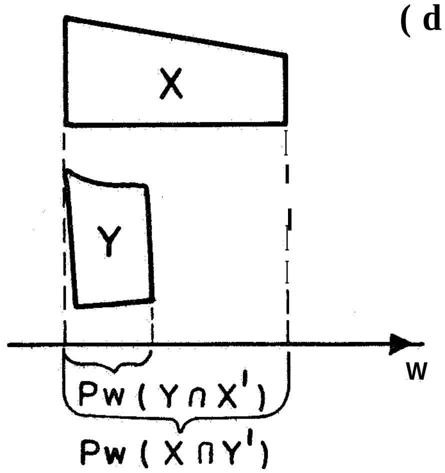
(b) THE PROJECTIONS CORRESPOND EXACTLY.
NOTATION: X ⊜ Y



(c) THE PROJECTION OF X CONTAINS THE PROJECTION OF Y, AND X PRECEDES AND FOLLOWS Y ALONG THE w AXIS.
NOTATION: X ⓛ Y

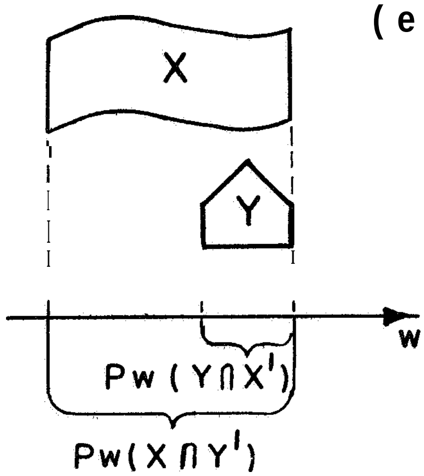
FIG. 4

EXAMPLES OF PRECEOENCE RELATIONS ALONG w AXIS



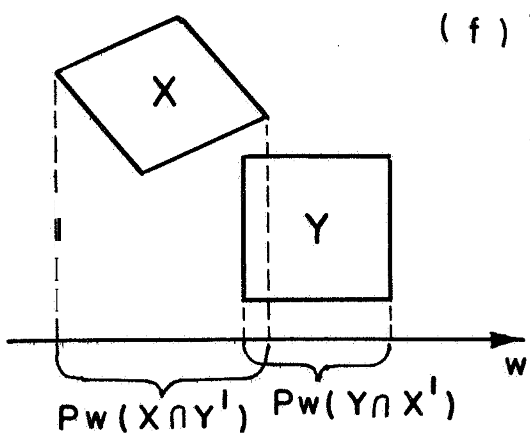
(d) THE PROJECTION OF X CONTAINS THE PROJECTION OF Y, AND X **FOLLOWS** BUT DOES NOT PRECEDE Y ALONG THE w AXIS.

NOTATION: X ≥ Y



(e) THE PROJECTION OF X CONTAINS THE PROJECTION OF Y, AND X PRECEDES BUT DOES NOT FOLLOW Y ALONG THE w AXIS.

NOTATION: X ≤ Y



(f) THE PROJECTION OF X CONTAINS PART OF THE PROJECTION **OF** Y, AND X PRECEDES Y ALONG THE w AXIS.

NOTATION: X $<>$ Y

FIG. 4 (CONTINUED)

(7) $(X < Y)$ & $(Y = Z) \rightarrow (X < Z)$

(8) $(X < Y)$ & $(Y \lessgtr Z) \rightarrow (X < Z)$

(9) $(X < Y)$ & $(Y \geq Z) \rightarrow (X < Z)$

(10) $(X < Y)$ & $(Y \leq Z) \rightarrow (X < Z)$

(11) $(X < Y)$ & $(Y <> Z) \rightarrow (X < Z)$

(12) $(X = Y)$ & $(Y \lessgtr Z) \rightarrow (X \lessgtr Z)$

(13) $(X = Y)$ & $(Y \geq Z) \rightarrow (X \geq Z)$

(14) $(X = Y)$ & $(Y \leq Z) \rightarrow (X \leq Z)$

(15) $(X = Y)$ & $(Y <> Z) \rightarrow (X <> Z)$

(16) $(X \lessgtr Y)$ & $(Y \geq Z) \rightarrow (X \lessgtr Z)$

(17) $(X \lessgtr Y)$ & $(Y \leq Z) \rightarrow (X \lessgtr Z)$

(18) $(X \lessgtr Y)$ & $(Y <> Z) \rightarrow (X \lessgtr Z)$ or $(X \leq Y)$ or $(X <> Z)$

(19) $(X \geq Y)$ & $(Y \leq Z) \rightarrow (X \lessgtr Z)$

(20) $(X \_ Y)$ & $(Y <> Z) \rightarrow (X \lessgtr Z)$ or $(X \leq Z)$ or $(X <> Z)$

(21) $(X \leq Y)$ & $(Y <> Z) \rightarrow (X <> Z)$

VI. RECONSTRUCTION ASSUMPTIONS

In the analysis of photographs there are several assumptions which might be employed in the various stages of reconstruction.

1) There could be symmetry about
   a) a point.
   b) a line.
   c) a plane.
   d) the boundary between the visible and the hidden portions of the object.
2) The boundary lines could be restricted to
   a) straight lines.
   b) circles or circle arcs.
   c) parabolic or higher order arcs.
   d) sine functions,
3) The object's surfaces could be made up of
   a) n-sided finite flat planes (polyhedral case).
   b) sections of spheres.
   c) sections of cylinders.
4) Configurations such as those shown in Fig. 5 have their standard or normal meaning.
5) There could be a volume or surface area restriciton.
6) The complete object could be restricted to a geometric class such as that of;
   a) convex figures
   b) non-convex, simply connected figures.

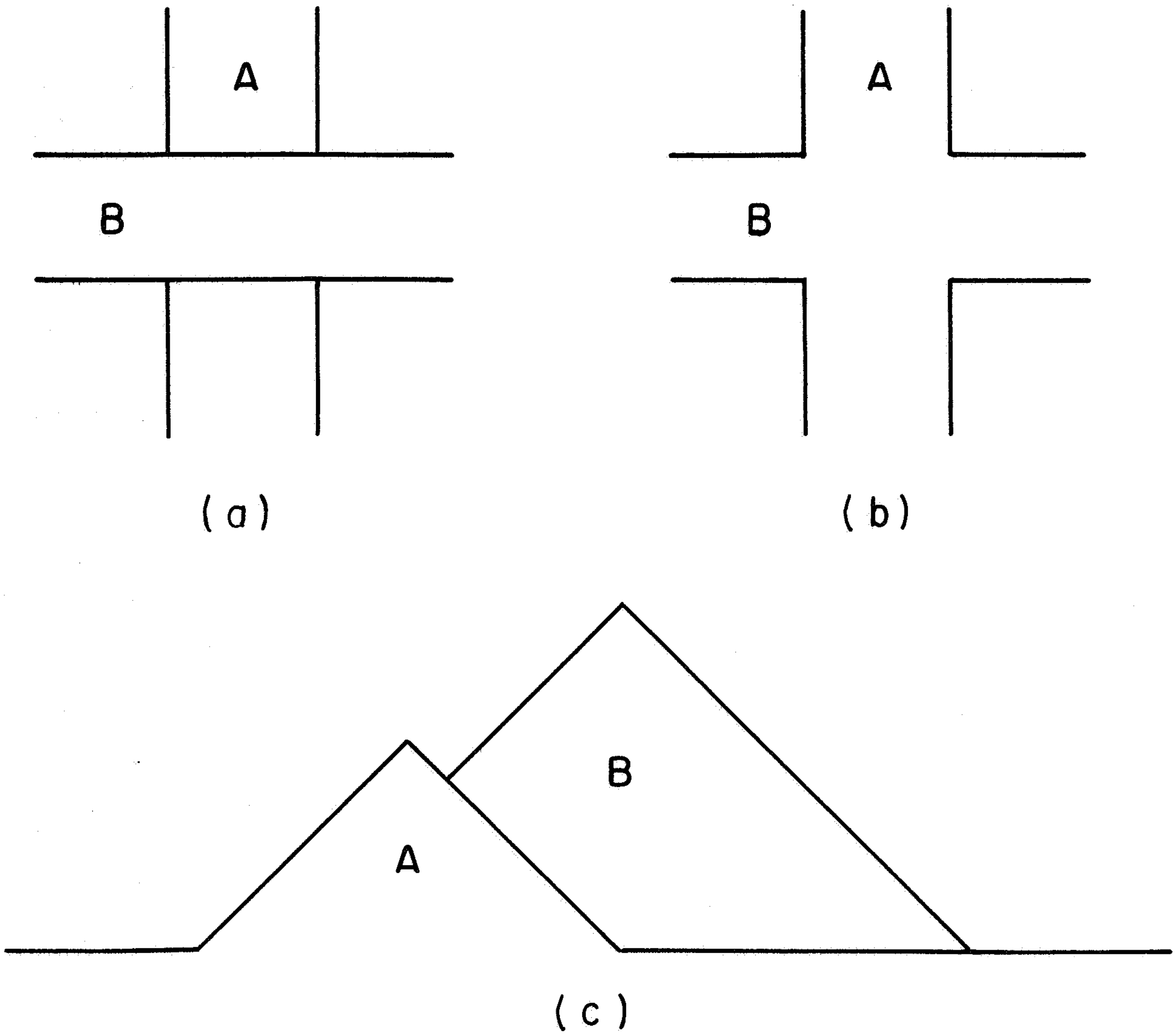


FIG. 5

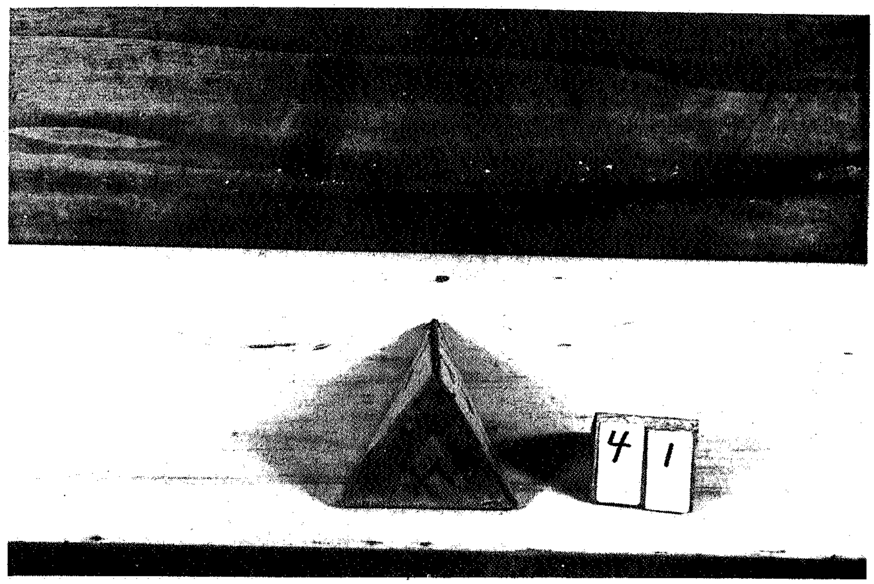
STANDARD AND NONSTANDARD INTERPRETATIONS OF SOME COMMON CONFIGURATIONS.
(w DEFINED AS NORMAL OUT OF THE PAPER)

FIGURE	STANDARD INTERPRETATION	NONSTANDARD INTERPRETATION
(a)	A PRECEDES B ALONG w.	A AND B AT SAME POINT ON w OR B PRECEDES A ALONG w.
(b)	A AND B AT SAME POINT ON w.	A PRECEDES B ALONG w OR B PRECEDES A ALONG w.
(c)	B PRECEDES A ALONG w.	A AND B AT SAME POINT ON w OR A PRECEDES B ALONG w.

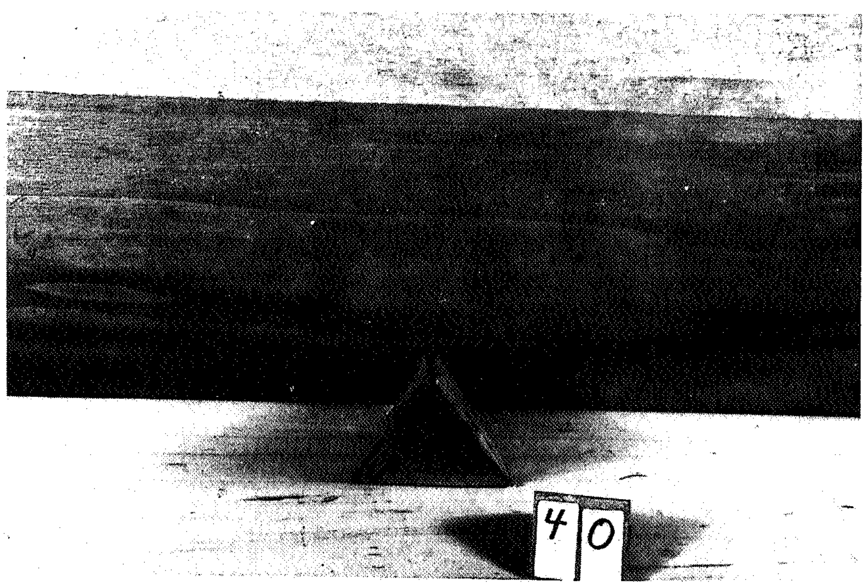
VII. CONCLUSIONS

The reconstruction of three-dimensional descriptions of objects from their photographs is a complicated and difficult task. Certain assumptions and step-by-step development of the necessary procedures are vital to *any* successful results. Furthermore, the pictures themselves can limit or aid in this success. For example, Fig, 2(b) shows three faces of each block, Fig. 3(b) shows two faces, and Fig, 3(a) shows only one face. Obviously, Fig. 2(b) would best facilitate the reconstruction, This seems to lead to a general rule; the best reconstruction is possible when the set of lines parallel to the axis of the lens intersects as many visible faces as possible at angles near 45°.

Two more points are brought out by Fig, 6 which shows two views of a tetrahedron. Neglecting markings and surroundings, faces T2 and T4 appear *to* be approximately the same size. Actually, the height of T2 is twice that of T4. Thus without additional information, reconstruction here would be impossible. One sort of additional information is in the shadows. If it were known or assumed that the lighting was the same for both photographs, then relative face size could be determined with the aid of the shadows on the right and left. However, if the lighting conditions were not known, the shadows would only add to the confusion.



(a)



(b)

FIGURE 6

TWO VIEWS OF A TETRAHEDRON

APPENDIX A: Data of Photographs

Film; **Plus X.**

Figure	f-stop	Shutter speed, sec.	Light no.	Light pos.	Focal length in mm.	X	Y	Z
2-a	11	1/100	1	F	58	0	-2	18
2-b	11	1/100	1	0	58	3	$\frac{1}{2}$	18
3-a	11	1/100	1	R	58	1	$\frac{1}{4}$	18
3-b	11	1/100	1	0	58	1	$\frac{1}{4}$	18
6-a	16	1/50	2	F,0 L & R	58+5 ext.	-	-	17
6-b	16	1/50	2	F,0 L & R	58+5 ext.	-	-	$16\frac{1}{2}$

Notation

no. = number of sources,

pos. = position of sources.

F = in front.

0 = overhead,

R = on the right,

L = on the left.

X = block separation, front to back,

Y = block separation, left to right,

Z = distance from the lens to the nearest point of subject,

Note: X, Y, and Z are given in inches.

APPENDIX B: Literature Survey

The articles in this survey were selected because of membership in one of the following catagories:

A) Tools which might prove useful in solving the problem,

B) Approaches taken on similar problems.

C) Papers which might lend insight to the problem..

All papers are numbered in chronological order, with the letters suffixed to the numbers indicating to which group the paper belongs. Papers with numbers prefixed with a star (*) have not been read, Papers with no comment were read but were deemed not pertinent.

An alphabetically arranged author index and a subject index are included at the end of the survey.

1aC Hawkes, H.E., et. al., Solid Geometry, Ginn and Company, New York, 1922.

Contains concise statements of the axioms, postulates, definitions, and theorems of basic solid geometry.

2C McCulloch, W.S., and Pitts, W., "How We Know Universals, The Perception of Auditory and Visual Forms," Bulletin of Mathematical Biophysics, Vol. 9, 1947.

3A Hilbert, D., and Cohn-Vossen, S., Geometry and the Imagination, Chelsea, New York, 1952.

A more advanced treatment of geometry than given in 1A.

4A Manual of Photogrammetry, American Society of Photogrammetry, Washington, 1952.

Mainly oriented towards aerial photography and map making, this manual does contain sections on the general optics and geometry of photography.

5A Dineen, G. P., "Programming Pattern Recognition," Proceedings of the Western Joint Computer Conference, March 1966.

Basic operations such as averaging, edging, and "blob" recognition are performed on a two level quantization of the input pattern.

6A Cahn, L., et. al., "Experiments in Processing Pictorial Information with a Digital Computer," Proceedings of the Eastern Joint Computer Conference, 1957.

The input pattern is quantized on two levels with a variable threshold drum scanner. Subroutines are presented for determining such properties as the total black area, the number of separate "blobs", and the image outlines.

7A Giesecke, Frederick E., et. al., Technical Drawing, Macmillan, New York, 1958.

This volume covers all aspects of technical drawing. The sections on perspective and projections are particularly pertinent.

8A Patterson, Boyd Crumrine, Projective Geometry, John Wiley and Sons, New York, 1958.

This is a clear and interesting presentation of the structure of projective geometry.

9A Sherman, H., "A Quasi-Topological Method for the Machine Recognition of Line Patterns," M.I.T. Lincoln Laboratories, Report No. 26-25-17, May 1959.

Although this paper is oriented toward character recognition, the techniques employed are general. A digitalized pattern is thinned and the resulting line pattern is examined for nodes and the manner in which they are interconnected.

10C Greene, F.H., "An Approach to Computers that Perceive, Learn and Reason," Proceedings of the Western Joint Computer Conference, March 1959.

This is a very abstract discussion, following an almost philosophical approach,

11A Unger, S.H., "Pattern Detection and Recognition," Proceedings of the IRE, Vol. 47, No. 10, pp. 1737-1752, October 1959.

This is a basic paper in pattern recognition. The effects of quantization are discussed, and descriptions are given of such basic operations as smoothing, and determining the edge sequence. Criterion and suggestions for a question tree are presented.

*12A Minot, O.N., "Counting and Outlining of 'Two-Dimensional' Patterns by Digital Computer," U.S. Naval Electronics Laboratory Report No. TM-414, August 1960.

13B Smi[illegible], A.F., "A Method for Computer Visualization," M.I.T. Electronics Systems Laboratories, Technical Memorandum 8346-Tm-2, September 1960.

A three-dimensional description is constructed from a three view orthographic projection. The process assumes that the object; 1) consists of plane surfaces; 2) is space filling; 3) has planes of bounded extent which are simply connected; and 4) only two planes can intersect at a given line. The point-line structure method of representation is used. Rules are given for determining all possible points and lines in the three-dimensional point-line structure from the information in the three two-dimensional point-fine structures. Additional rules are stated for eliminating the extraneous lines and points in the three-dimensional point-line structure.

14A "A Method of Mechanization of Geometry," Cybernetica, Vol. 3, No, 2, pp. 38-116, and Vol. 3, No. 4, pp. 301-311, 1960 (in French).

*15A Sprick, W., and Canzhorn, X., "Method for Pattern Recognition by Following the Boundary," Proceedings of the International Conference on Information Processing, Paris, pp, 238-244, 1960.

*16A Wholey, J.S., "The Coding of Pictorial Data," IRE Transactions on Information Theory, Vol. IT-?, No. 2, April 1961.

17C Frick, F.C., "Pattern Recognition," Proceedings of the Western Joint Computer Conference, May 1961.

This is a general. discussion of the field with the emphasis on the problems of automatic speech recognition.

18A Freeman, H., "Techniques for the Digital Computer Analysis of Chain-&coded Plane Curves." Proceedings of the National Electronics Conference, Vol. 17, pp. 421-432, October 1961.

The basic terms and properties of "chain-encoding" are introduced. Methods are described for the analytical determination of such quantities and qualities as height, length, area, symmetry, moments, and intersections of "chain-encoded" plane curves.

19A Glass, J.M., "Analysis of Quantized Two-Dimensional Geometric Patterns," N.Y.U. Technical Note 400-7, September 1961,

A study is made of the effects of quantizing plane curves, A statistical model is developed for square box quantization, Other methods of quantizing are examined but no models seem to be possible,

20A Freeman, H., "A Classification and Recognition Technique for Geometric Patterns," N.Y.U. Technical Report 400-33, July 1961.

Descriptions are given of chain encoding and chain difference encoding of plane curves. The use of chain autocorrelation functions for pattern classification, and chain crosscorrelatioa functions for pattern recognition is suggested, A recognition coefficient and discrimination factor are defined.

21 Simmons, P.L., and Simmons, R.F., "The Simulation of Cognitive Processes: An Anotated Bibliography," IRE Transactions on Electronic Computers, Vol. EC-10, No, 3, 1961.

The emphasis in this survey is on computer problem solving, character recognition, and models of the human brain and nervous systemm.

22 Simmons, P.L., and Simmons, R.F., "The Simulation of Cognitive Behavior, II; An Annotated Bibliography," Systems Development Corporation Report SP-590/002/00, 1961,

A, continuation of 21.

23AC Green, B.F., "Computer Models for Cognitive Processes," Pyschometrika, Vol. 26, No, 1, 1961,

General discussion.

24C Murdock, B.B., and Warhurst, F,, "The Recognition of Tri-Dimensional Stimuli," University of Vermont, Burlington, January 1962,

A statistical study of the ability of human subjects to recognize tri-dimensional stimuli is presented. The dimensions considered are color, form and crosshatching, 25A "Principies of a Natural Image Computer," Ford Aeronutronics, February 1962.

A novel idea for the processing of images using optical techniques is presented, Not enough information is given to reach *any* conclusion.

26A Narasimhan, R., "A Linguistic Approach to Pattern Recognition," University of Illinois, Digital Computer Laboratory Report No, [illegible], July 1962.

This report is prerequisite to 33A. A method of analyzing patterns by studying their structure is presented, Of special interest is a section discussing methods and criteria for repairing noisy pictures.

27A Freeman, H., 'On the Digital Computer Classification of Geometric Line Patterns," N.Y.U. Technical Report 400-65, August 1962.

This is an extension of 18A and 20A. The directionality spectrum and the asymmetry spectrum, two orientation dependent properties, are introduced. Curvature, an orientation independent property, is investigated.

28AC Kao, R.C., "The Use of Computers in the Processing and Analysis of Geographic Information," Rand Corporation, Santa Monica, California, August 1962,

29AC Ruttenberg, K, "Digital Computer Analysis of Arbitrary Three-Dimensional Geometric Configurations," N.Y.U. Technical Report No, 400-69, October 1962,

Three-Dimensional application of Freeman's chain-encoding of 18A.

30 Fenton, R., "Survey on Research on Automatic Pattern Recognition," Ohio State University, Antenna Laboratory, December 1962.

The introduction describes, in general terms, scanners, types of recognition techniques, and application requirements. The remainder is involved primarily with character recognition,

*31C Michels, K.M., and Pitts, L., "Geometricity of Visual Forms," Perceptual and Motor Skill, Vol. 14, pp. 147-154, and Vol. 15, pp. 55-58, 1962.

*32A Clarke, A.B., "A Photographic Edge Isolation Technique," Photogrammetric Engineering, Vol. 38, pp. 393-399, 1962.

33A Narasimhan, R., " A Programming Language for the Parallel Processing of Pictures," University of Illinois, Digital Computer Laboratory Report No, 132, January 1963.

The system described operates on a binary quantization of the input picture, An extension of ALGOL-60 is devise? for the manipulation of picture data. The use of the language for simple processing routines is illustrated.

34AC Sutherland, I.E., "Sketchpad, A Man-Machine Graphical Communication System," Thesis, M I.T., January 1963.

Input-output is provided by a combination of light-pen, cathode ray tube display, and a series of switches and controls. Two-dimensional figures are constructed from straight line segments and circle arcs. Facility is provided for such functions as rotation, compression, expansion, translation, and the imposition of geometric constraints, An important feature of the system is the ring structure data storage designed to allow rapid location and manipulation.

35B Roberts, L.G., "Machine Perception of Three-Dimensional Solids," M.I.T., Lincoln Laboratories, Technical Report R 315, May 1963.

A method for determining three-dimensional descriptions of solids from their photographs is presented under the assumptions that the solids are bounded by planar faces and that they are somehow supported, The method uses three steps. First, the picture is reduced to a line drawing. Second, a three-dimensional description of the object is constructed from the line drawing and a set of simple models, Finally a display program produces a two-dimensional view of the object from any point of view,

36AB Johnson, T.E., "Sketchpad III, Three-Dimensional Graphical Communication with a Digital Computer," M.I.T. Electronic Systems Laboratory, Report ESL-TM-173, May 1963.

A combination of 34AC and 35B enable the Sketchpad user to work in three-dimensions. Three orthogonal views plus a perspective view of a three-dimensional wire frame figure are drawn and manipulated on the two-dimensional oscilloscope screen.

37A Ruttenberg, K., "Algorithms for the Encoding of Three-Dimensional Geometric Figures," N.Y.U. Technical Report No, 400-86, June 1963.

Extension of 29AC. Algorithms for encoding basic forms such as planes and conic sections are developed. As an example of the methods usefulness, an algorithm is described for determining the intersection of a plane with a closed convex surface.

38AB Leland, H.R. et. al., "Application of Perceptrons to Photo-interpretation," Cornell Aeronautical Laboratory, Buffalo, New York, Report No. VE-1.446-G-3, August 1963.

This report contains a brief summary of the work done over the previous three years on the development of a perceptron system capable of detecting and recognizing objects in aerial photographs,

39A Cherry, C., et. al., "An Experimental Study of the Possible Bandwidth Compression of Visual Image Signals," Proceedings of the IEEE, Vol. 51, No, 11, pp. 1507-1517, November 1963.

A survey of the experimentation completed up to 1963 is presented,

40C Warntz, W., "Geography, Geometry and Graphics," Princeton University, 1963.

41AB Leonardo, E.S., "Comparison of Imaging Geometry for Radar and Camera Photographs," Proceedings of the American Society of Photogrammetry Meeting, Washington, D.C., March 1964.

The main concern of this report is the distortion existing in side looking radar images.

42C Rushforth, C.K., "Recognizing Patterns in Photographs," Utah State University, Electro-Dynamics Laboratories, Logan Utah, May 1964.

This report is concerned with determining which of a set of known patterns is embedded in noise or background radiation,

43A Knight, J.M., et. al., "Digital Television: Shrinking Bulky Bandwidths," Electronics, Vol. 37, No. 31, pp. 77-84, December 1964.

44C Silver, C.A., "Multidimensional Analysis of Visual Form," Franklin Institute, Laboratories for Research and Development, Philadelphia, December 1964.

45C Logan, T., "Estimation and Reproduction of Angles from a Given Line of Reference," Perceptual and Motor Skills, Vol. 18, pp. 231-234, 1964.

A statistical study is presented of the ability of human subjects to estimate and reproduce angles between 15° and 90° with reference to a given line,

46C Blum, H., "A Transformation for Extracting New Descriptors of Shape," Symposium on Models for Perception of Speech and Visual Form, Boston, November 1964.

A method of generating forms by the propagation of variously shaped wave fronts is described, The critical points of the form are the points where the wave fronts meet.

47C Clowes, M.B., "An Hierarchical Model of Form Perception," Symposium on Models for Perception of Speech and Visual Form, Boston, November 1964.

Picture processing operations are defined as; 1) describing; 2) addressing; and 3) labelling. A study is presented of the use of neighborhood operations.

48A Freeman, H., "On the Classification of Line-Drawing Data," Symposium on Models for Perception of Speech and Visual Form, Boston 1964.

Grid intersection chain encoding is used (see 18A). Small chains called chainlets are formed. Classification may be accomplished by comparing the bays and peninsulas in the chains and chainlets.

49A Rosenf'eld, A., et. al., "Pattern Recognition: IV Sequential Operations in Digital Picture Processing," University of Maryland, Computer Science Center, College Park, Maryland, 1965.

Sequential versus parallel operations on digitalized pictures are discussed. Transformations such as thinning and smoothing are performed using neighborhood operations. A "distance skeleton" is introduced which transforms a picture into "quasi line forms."

*50A Bisignani, W.T., et. al., "The Improved Gray Scale and the Coarse-Fine PCM Systems, Two New Digital Bandwidth Reduction Techniques," Proceedings of the IEEE, Vol. 54, No. 3, pp. 376-390, March 1966

51 Kause, R.H., "Interpretation of Complex Images Literature Survey," Goodyear Aerospace Corporation, Akron, Ohio, February 1965.

The survey contains studies of human perception under various conditions of distortion, movement and background,

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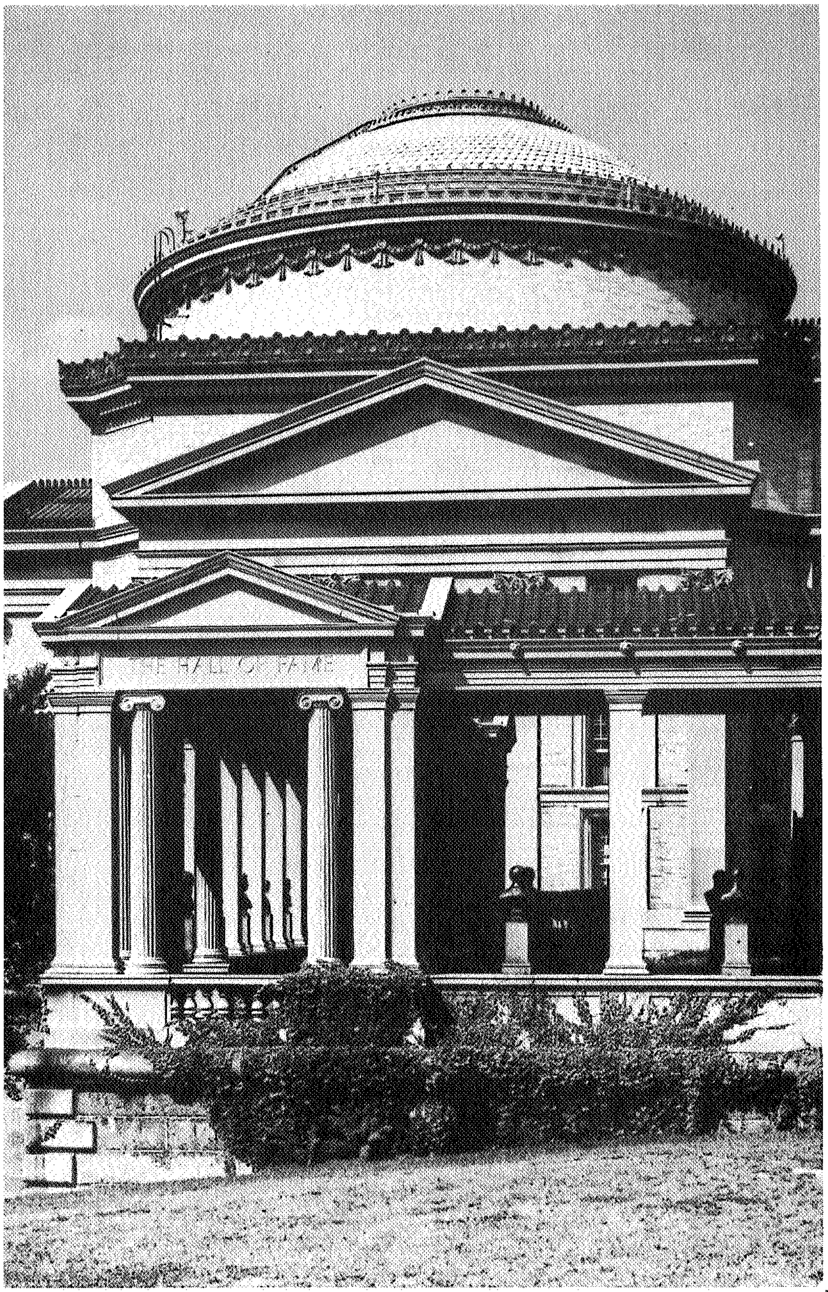

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